

Toward quantum regime of thermal transport by a new generation of membrane-based attowatt-calorimeter

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With use of nano-engineered systems, we can alter the fundamental properties of materials, and consequently a new sets of applications will emerge. This fact has been illustrated particularly in thermal properties of confined systems¹. However especially at low temperature or in amorphous structures, the fundamental mechanisms of heat transport in nanowires² or membranes³ is still lacking. When the phonon characteristic lengths like the mean free path or the dominant wavelength, exceed that of lateral dimensions of the system, the whole thermal transport will be governed by boundary scattering, which goes from fully diffusive (Casimir) to ballistics (Landauer).^{2,4}

When the specular reflection becomes dominant by the surfaces, the phonon contribution will be ballistic. At this state, we shall demonstrate the transition from the Ziman-Casimir regime to the fully ballistic regime. In this regime only four acoustic modes are occupied, and the thermal conductance is expected to show a linear temperature dependence with the maximum possible value of $G_{NW} = 4q$ where, $q = (\pi^2 k_B^2)T/3h$ is the universal value of quantum of thermal conductance.⁴

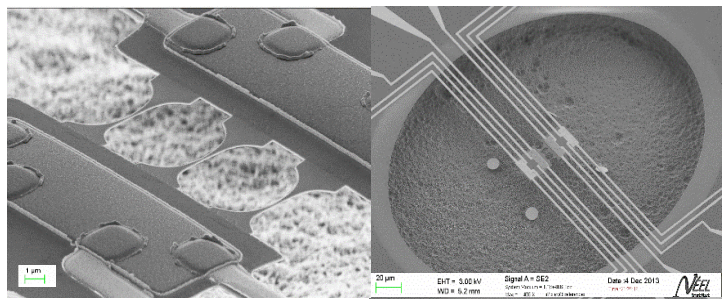


Figure 1: Side view of membrane-based nano-calorimeter made from high stress amorphous Si_3N_4 , bridged by 1D channels. Each platform contains a heater and a

For this scientific objective we have elaborated a new suspended membrane based nano-calorimeter based on differential geometry (see Figure 1) adapted to very low temperature measurement with unprecedentedly ~ 5 Attowatt sensitivity. The calorimeter consists of two adjacent platforms, each of them contains a heater and a resistive thermometer (NbN). The bridged nanowire is designed to be of the same material to avoid any kind of thermal contact resistances. We established an experimental protocol based on the estimation of heat flow through the suspended beams of each membrane, then by using ultra-sensitive thermometry we know the exact temperature of each membrane. Now we are able to measure the thermal conductance of 1D phonon wave guide between two reservoirs.

As an overview, we have developed an ultra-sensitive attowatt-calorimeter, adjusted to low temperature measurement, with negligible any kind of contact thermal resistance and thermal radiation. The perspective of the work is to cross over the Casimir regime, and enter into the quantum transport of heat in low dimension conductors.

¹ David Cahil et al, *Appl.Phys.Rev*, **1**, 011305 (2014).

² Jean-Savin Heron et al, *Phys.Rev.B*, **82**, 155458 (2010).

³ Hossein Ftouni et al, *Phys.Rev.B*, **92**, 125439 (2015).

⁴ J.M Ziman, *electrons and phonons*, Clarendon Press, Oxford (2001).